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The effect of direction of movement on information capacity of discrete motor responses for sixth grade students

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THE EFFECT OF DIRECTION OF MOVEMENT
ON INFORMATION CAPACITY OF DISCRETE
MOTOR RESPONSES FOR SIXTH GRADE STUDENTS

by

Roger Lee Redelman

United States
Naval Postgraduate School

THESIS

THE EFFECT OF DIRECTION OF MOVEMENT

ON INFORMATION CAPACITY OF DISCRETE

MOTOR RESPONSES FOR SIXTH GRADE STUDENTS

by

Roger Lee Redelman

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The Effect of Direction of Movement

on Information Capacity of Discrete

Motor Responses for Sixth Grade Students

by

Roger Lee Redelman
Major, United States Marine Corps
B.S., Saint Joseph's College, 1959

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the
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ABSTRACT

This study reports an investigation designed to determine the effect of direction of movement on the information capacity of discrete motor responses. Reaction times and movement times were measured for thirty right-handed sixth grade students completing discrete motor tasks in response to a visual stimulus. Times for seven different directions over three indexes of difficulty were compared. Results showed that direction had no significant effect on reaction times. Results reconfirmed the findings of previous studies that movement time is a linear function of index of difficulty. In addition, the results showed that direction does have a significant effect on the movement times of discrete motor responses. A multiple linear regression formula: Movement Time = -30.32+100.03 (Index of Difficulty) -3.27 (cosine of the angle of movement); was developed which might be used to predict movement times.

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I. INTRODUCTION

An interesting relationship was developed by Fitts (Ref. 1) as a result of experimentation concerning the information capacity of the human motor system in controlling the amplitude of movement. An index of difficulty (ID) of a movement was proposed by this experimentation which demonstrated for serial tasks, that the minimum amount of information required to produce a movement having a particular average amplitude plus or minus a specified tolerance (variable error) is proportional to the logarithm of the ratio of the tolerance to the possible amplitude range. The average rate of information generated by a series of movements is then the average information per movement divided by the time per movement. Later experimentation by Fitts and Peterson (Ref. 2), Fitts and Radford (Ref. 3), and Breen, DeHaemer, and Poock (Ref. 4) has confirmed that this same type of relationship holds for discrete movements as well as serial responses.

Fitts and Peterson (Ref. 2) examined the information capacity of discrete motor responses. This experimentation investigated the relationship between the information contained in a discrete motor response, the movement time (MT) to accomplish the response, and the reaction time (RT) for the decision process to take place. In this investigation, the discrete motor responses to a visual stimulus consisted of movements of equal distance to targets to the left and right of a starting point. The

index of difficulty (ID) was defined as:

$$ID = \log_2 \left[\frac{2A}{W} \right] ;$$

where A is the movement amplitude between the starting button and the target and W is the target width. Correlation between ID and MT was found to be over 0.99 for the ID range used in the experimentation. The resulting analysis showed a linear relationship MT = a + b (ID) and a relative independence between reaction time and movement time.

Fitts and Radford's (Ref. 3) findings from two experiments concerning information capacity of discrete motor responses under different cognitive sets support the results of the previous studies. Again the index of difficulty (ID) defined as the amount of information that the movement is required to generate, was defined as:

$$ID = \log_2 \left[\frac{2A}{W} \right] \text{ bits};$$

where amplitude A, is the distance from initiation to average termination of the movement and accuracy W, is defined as the permissible range within which the movement may terminate. Again, results of analysis demonstrated that MT increased linearly with ID and that a relative independence existed between MT and RT.

Finally, Breen, DeHaemer and Poock (Ref. 4) essentially duplicated Fitts and Peterson's (Ref. 2) experiment and added an auditory stimulation to the visual stimulus previously studied. Analysis of their results reconfirmed the equation MT = a + b (ID), for both visual and audio stimulus.

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In the above cited experiments, the subjects' movements were made to the right and left of a starting point in response to a stimulus. Many tasks that are required to be performed include movements in many other directions besides the movement to the right or left of a starting position. What, if any, are the effects of direction of movement on the information capacity of discrete motor responses? The basic purpose of the experimentation reported here is to determine the effects of direction of movement on the reaction and movement times of subjects completing discrete motor tasks in response to visual stimulus.

II. METHOD

A. APPARATUS AND TASK

The basic apparatus designed to determine what are the effects of direction of movement on the information capacity of discrete motor responses consisted of 2 ft. by 4 ft. board with twenty-one copper disk targets one inch in diameter and a copper screw head starting position mounted on it. (See Figure 1.) The twenty-one targets were arranged in three rows for seven different directions of movement starting with 0°, the direction directly to the right of the starting position. The three targets were located in each of the seven directions at distances of four, eight, and sixteen inches respectively. The directions radiate from the starting position in 30° increments from the initial 0° direction to the right of the starting position using the cartesian coordinate system. Thus the index of difficulty (ID) for targets 1 through 7 equals 3; 8 through 14 equals 4; and 15 through 21 equals 5 from the formula:

$$ID = \log_2 \left[\frac{2A}{W} \right] \text{ bits};$$

where A is the amplitude of movement from the starting position to the target center and W is the diameter of the target area. Attached to the board was a metallic tipped probe with a wire extension extending from the probe sufficiently long to easily move the probe from the starting position to the furthest target row.

At a direction of 90° or directly to the front of a subject sitting at the apparatus was a light located 21 inches from the starting position.

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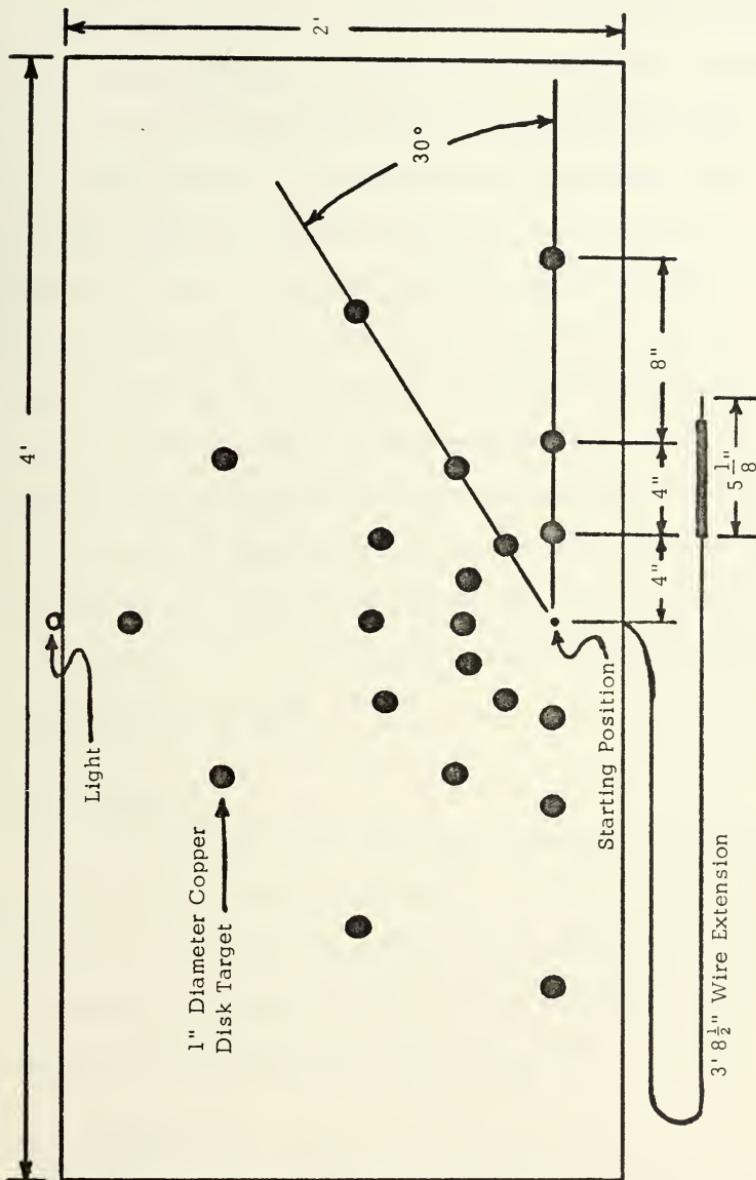
FIGURE 1. DIAGRAM OF BASIC EXPERIMENTATION APPARATUS

2'

4'

30°

8"

4"

4"

$5\frac{1}{8}$"

Light

1" Diameter Copper
Disk Target

Starting Position

$3'8\frac{1}{2}$" Wire Extension

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This light was used as the visual stimulus to which the subject was to react. Two timers electrically connected to the board and a probe were used to measure, to the nearest 1/100th of a second, the reaction time to the visual stimulus and the total time for the response. The reaction time (RT) to the visual stimulus consisted of the time it took the subject to remove the probe from the starting position after the light to the subject's front came on. The total time consisted of the time from the lighting of the light until the subject removed the probe from the starting position, moved it to the pre-designated target, and touched the target. The movement time (MT) for each discrete motor response was determined by subtracting the reaction time from the total time. The basic task consisted of the subject watching for the light to the front to light up and moving the probe as rapidly as possible from the starting position to the pre-designated target.

B.   SUBJECTS

Thirty right-handed volunteer sixth grade students 11-12 years of age were used as subjects in this experiment. Of the group, 19 were boys and 11 were girls. Those who habitually wore glasses were required to wear them during the experiment. The IQ's of the subjects, determined by Lorge-Thorndike Intelligence tests, ranged from 95 to 140.

C.   PROCEDURE

Subjects were given standard instructions (Appendix A). Before beginning the actual experimental session each subject took part in a

sufficient number of practice trials until the experimenter was sure that the subject was at ease and knew exactly what to do during the actual experiment. Each subject performed a total of 105 trials, i.e. 5 trials to each target, of the basic task of reacting to the visual stimulus and moving the probe as rapidly as possible to a pre-designated target. After each set of twenty-one trials the subject was given a rest break besides the short rest periods between trials. Approximately 3 trials were given per minute during the experiment.

A randomizing procedure was used to determine the order of the twenty-one pre-designated targets to be called out to the subjects in each of the five runs.

Subjects were carefully observed throughout the experiment to see if the subject hesitated before moving or otherwise missed the target area with the probe, sliding it into the target. When this occurred, which was very infrequently, the trial was repeated and the miss disregarded.

III.   RESULTS

The thirty subjects performed five trials for each of the three ID's
and seven directions of movement, that is, for the twenty-one targets
after an initial practice run for familiarization. The times for practice
trials were not recorded. Subsequent analysis verified previous experi-
ence that no learning occurred during the experiment, and each measured
response was therefore considered independent. The results for reaction
times and movement times were analyzed separately.

A.   REACTION TIMES

Figure 2 shows an initial comparison for reaction time data for the
three ID's over the seven different directions in which the discrete motor
responses were made. Figure 2 shows little change in reaction times
over the seven directions of movement. Figure 2 also indicates that
changes in ID only have a small effect on reaction time.

The reaction time data were analyzed by a two-way analysis of
variance (Ref. 5). The results of the analysis are shown in Table I.
From Table I, it is apparent that no statistical significant difference
existed among the seven directions for reaction times, but that a differ-
ence existed among the three ID's at the 0.01 level of significance.
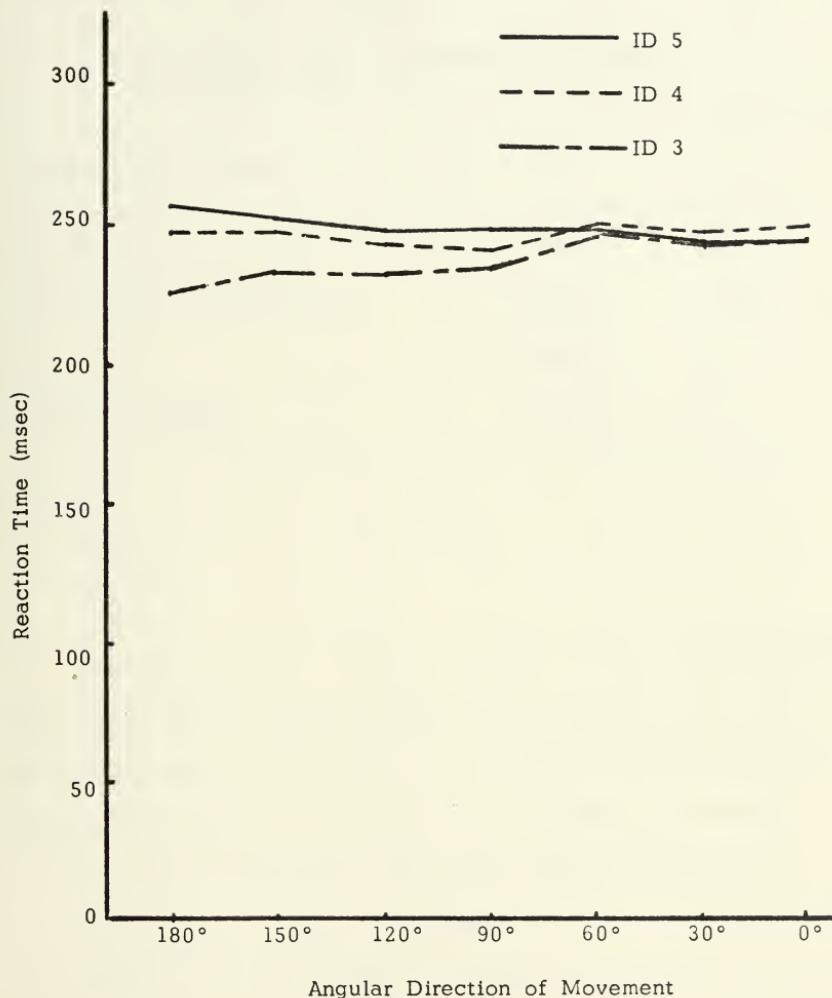
FIGURE 2. INITIAL COMPARISON OF REACTION TIME DATA

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TABLE I

ANALYSIS OF VARIANCE ON REACTION TIME DATA

SOURCES OF VARIATION	df	MS	F
INDEX OF DIFFICULTY (ID)	2	0.04026	17.132 **
DIRECTION OF MOVEMENT (D)	6	0.00345	1.468
(ID) x (D)	12	0.00503	2.14 *
WITHIN REPLICATES	3129	0.00235	-----
TOTAL	3149		

** $p < 0.01$

* $p < 0.05$

Regression and correlation analysis were performed on the reaction time data for each of the seven directions of movement (Ref. 5). The correlation between mean reaction time and ID for the seven directions ranged from 0.002 for 0° to 0.248 for 180° direction of movement. Figures 3-9 show the reaction time linear regression equations for each of the seven directions of movement. These results demonstrate that changes in ID values have a constant but small effect on reaction time.

In addition, since the analysis of variance showed that no statistically significant difference existed for reaction time among the seven directions in which movements were made, a single linear regression

was performed on the reaction time data combined for all seven
directions. The resulting equation for predicting reaction is given
as follows: Reaction Time = 5.62 (ID) + 222.67 with a correlation between
mean reaction time and ID of 0.64.

B.   MOVEMENT TIMES

Figure 10 shows an initial comparison of movement time data
for the three ID's over the seven different directions in which the
discrete motor responses were made. This initial comparison of raw
data indicates a sharp increase in mean movement times as the ID
was increased for each direction in contrast to the small increase
in the reaction times as shown previously.

The movement time data were analyzed by a two-way analysis
of variance (Ref. 5). The results of the analysis are shown in
Table II. From Table II, it is apparent that a statistically significant
difference does exist among the seven directions as well as among
the three ID's.
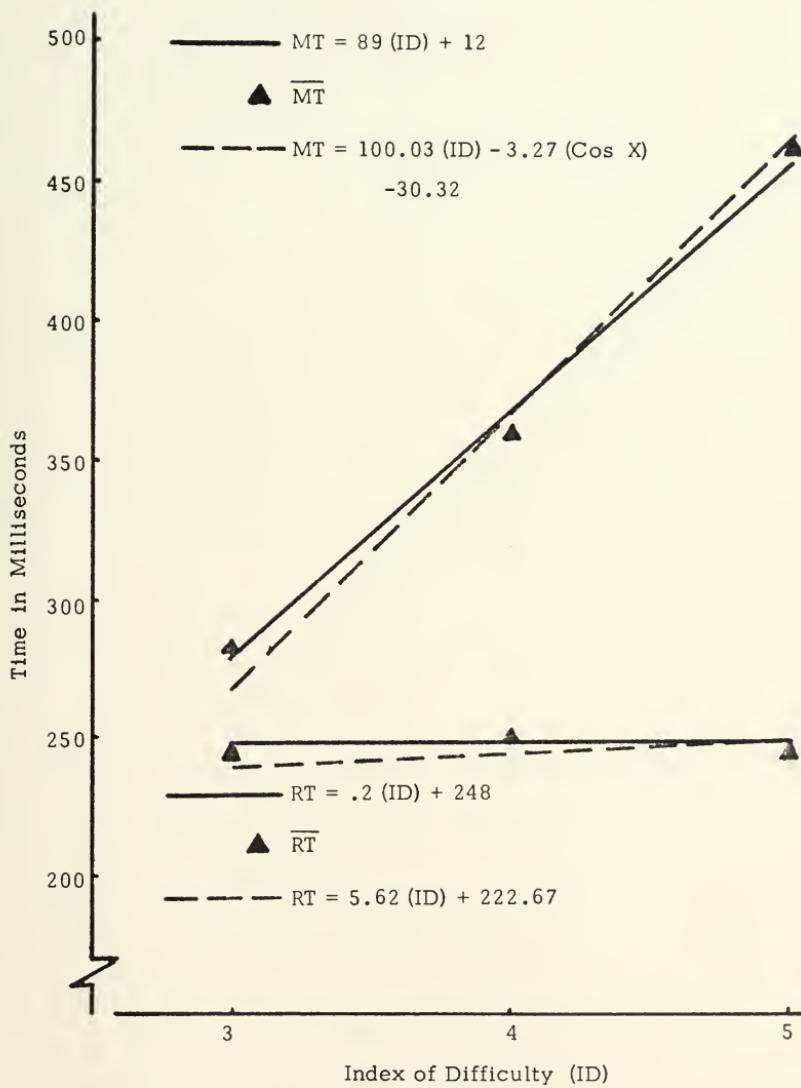
FIGURE 3. RESULTS FOR 0° DIRECTION OF MOVEMENT

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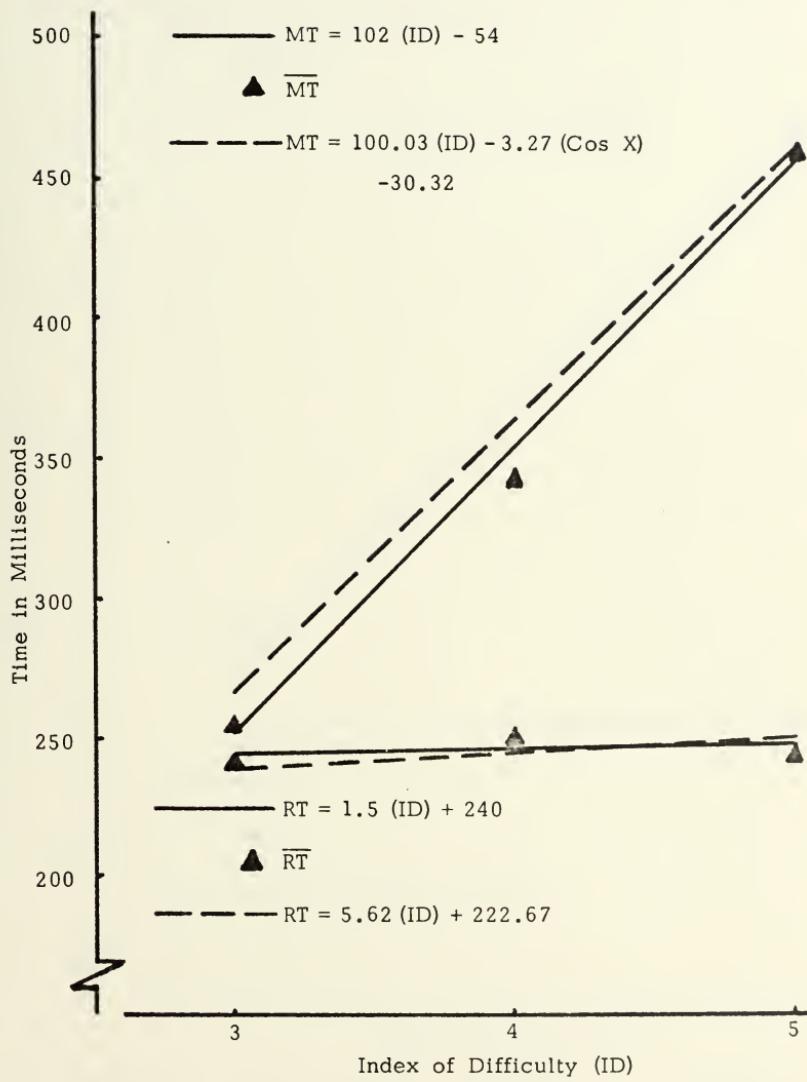
FIGURE 4. RESULTS FOR 30° DIRECTION OF MOVEMENT

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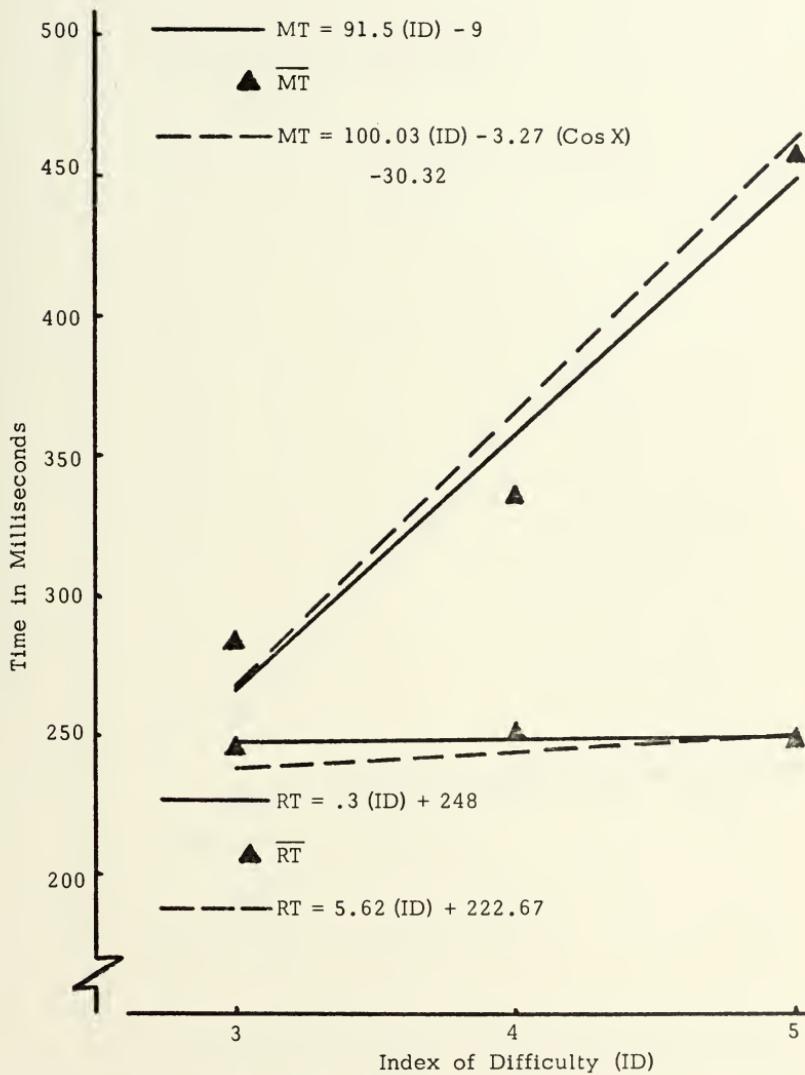
FIGURE 5. RESULTS FOR 60° DIRECTION OF MOVEMENT

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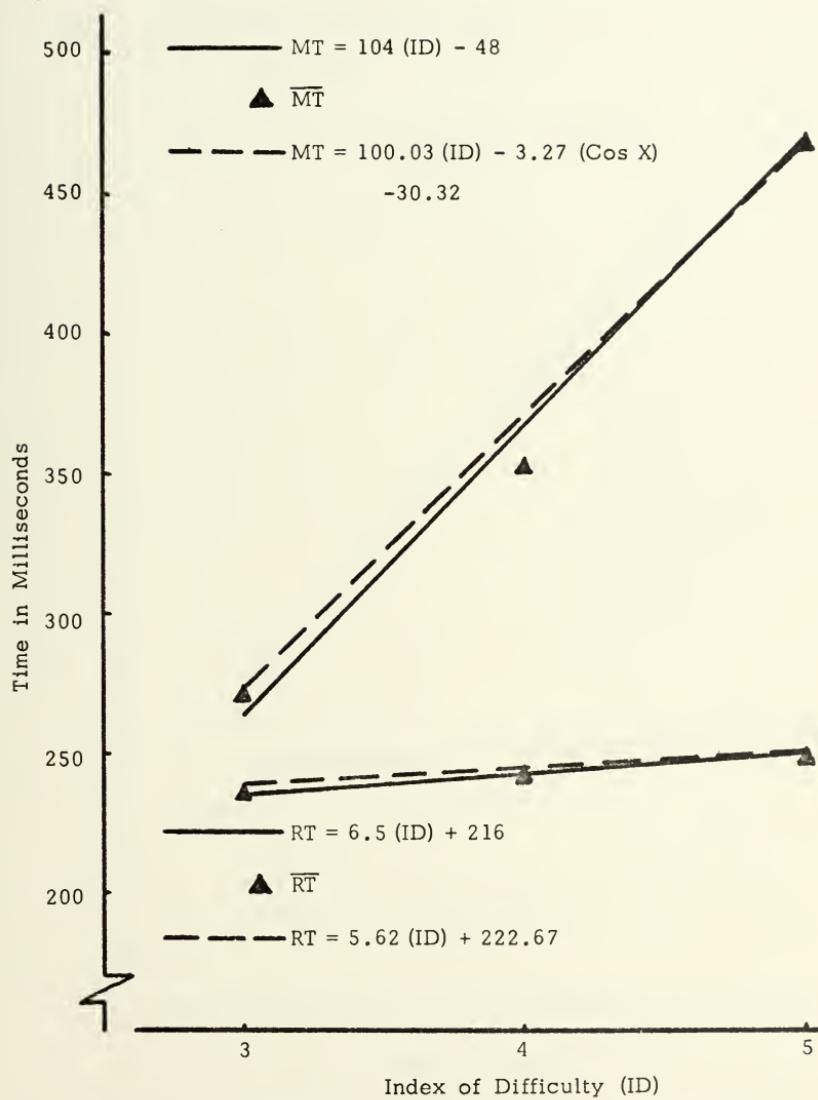
FIGURE 6. RESULTS FOR 90° DIRECTION OF MOVEMENT

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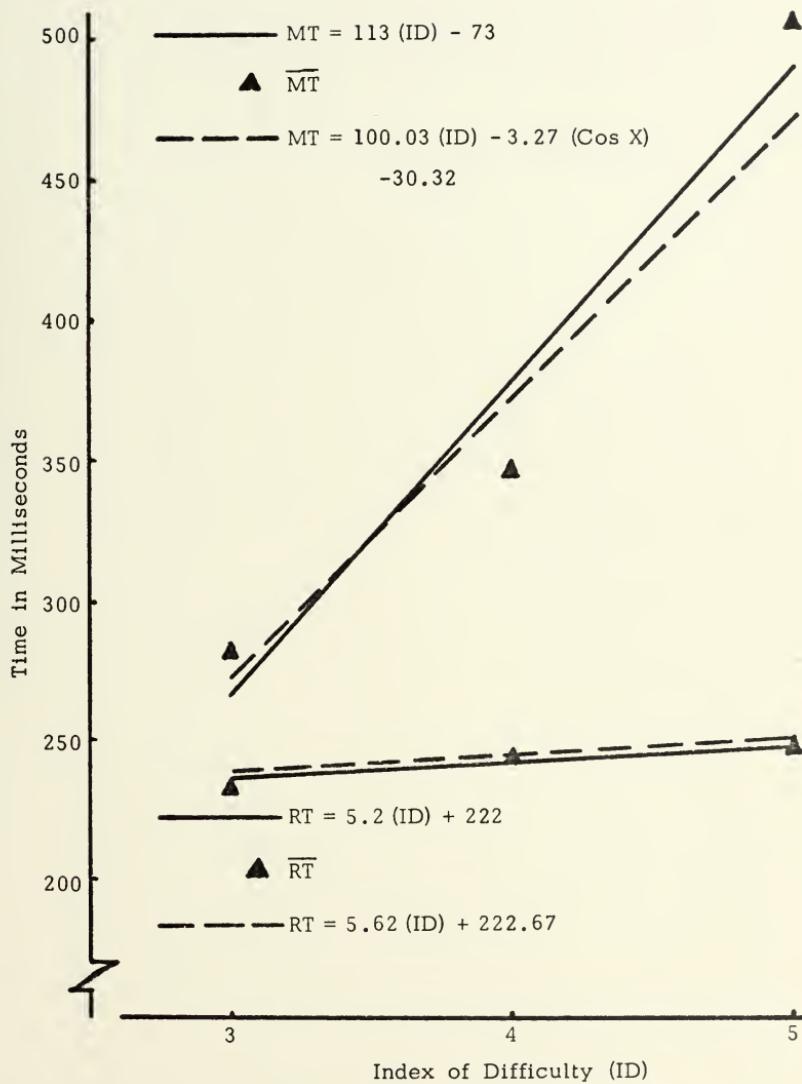
FIGURE 7. RESULTS FOR 120° DIRECTION OF MOVEMENT

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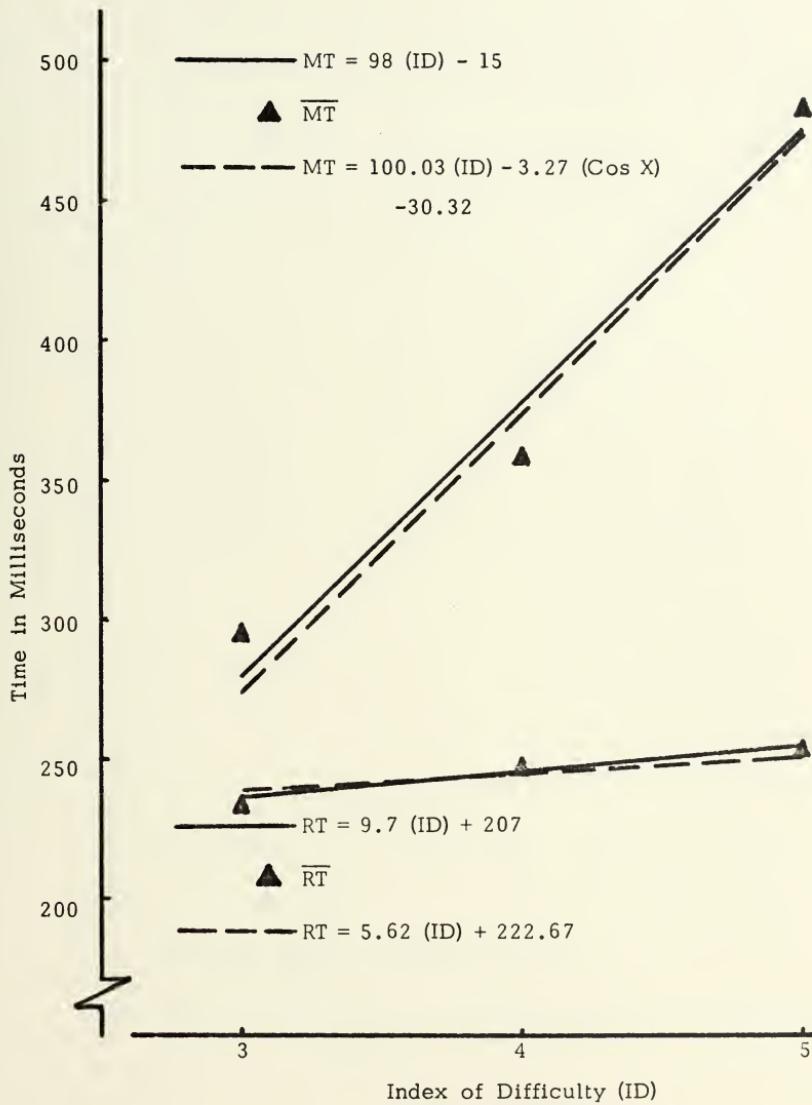
FIGURE 8. RESULTS FOR 150° DIRECTION OF MOVEMENT

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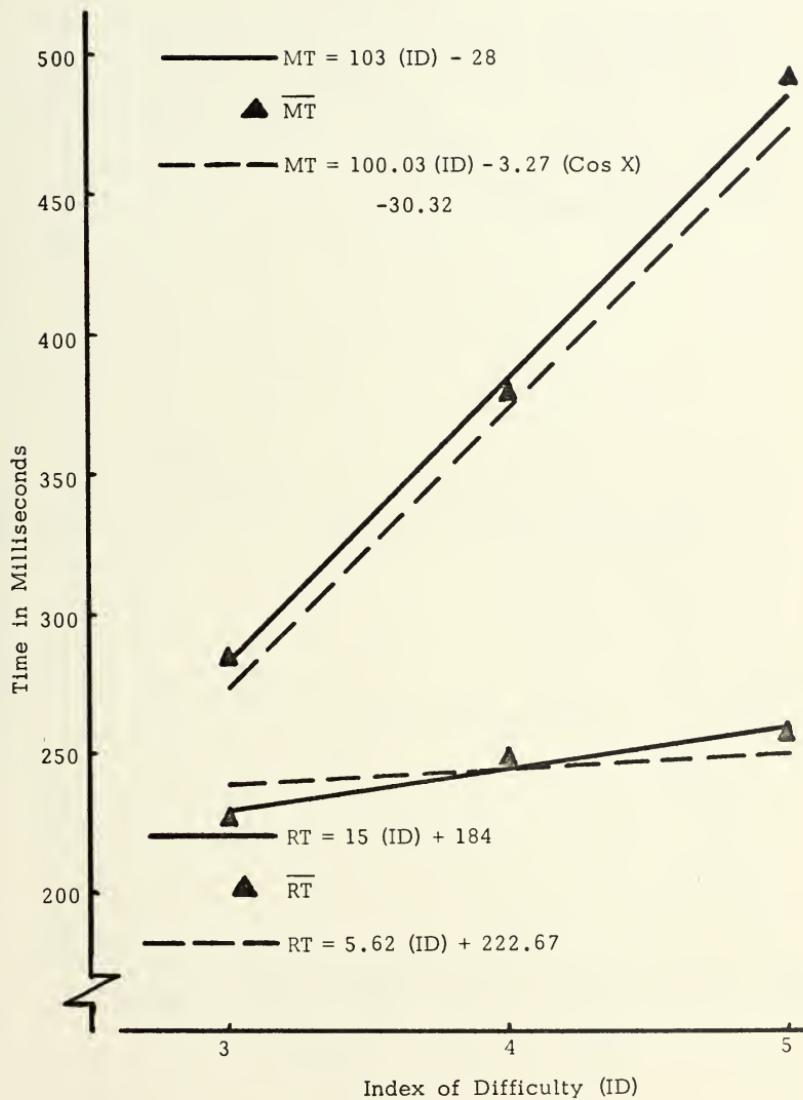
FIGURE 9.   RESULTS FOR 180° DIRECTION OF MOVEMENT

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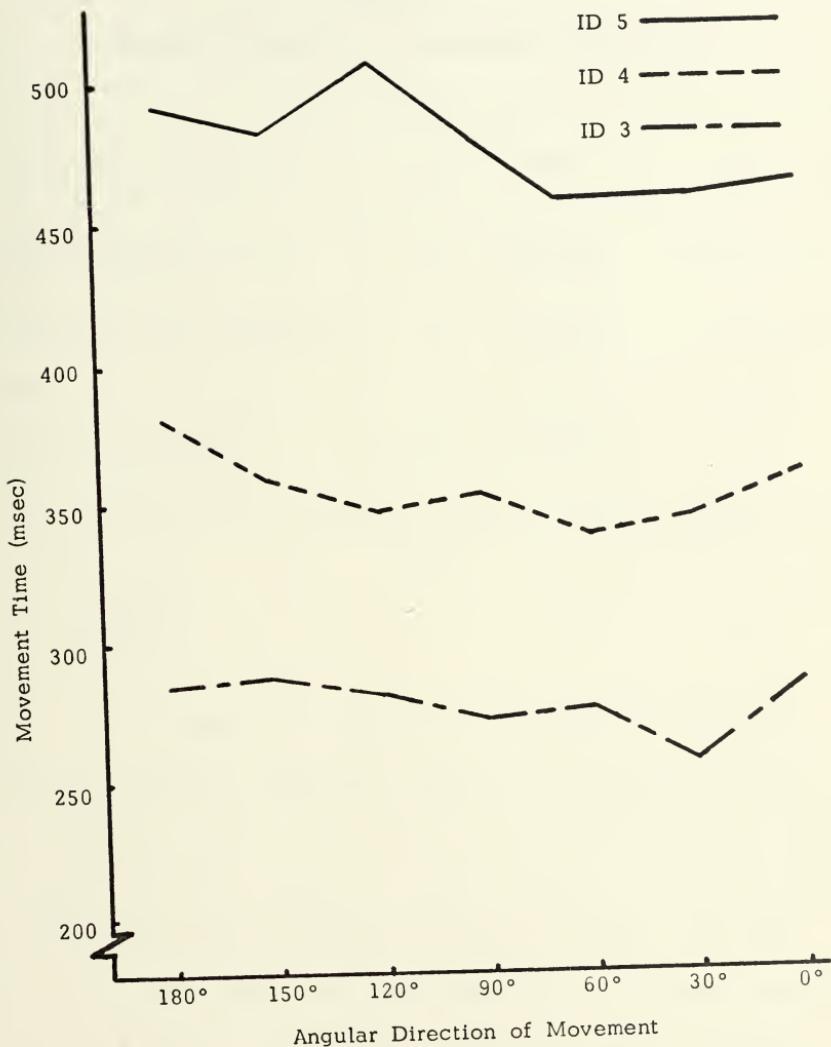
FIGURE 10. INITIAL COMPARISON OF MOVEMENT TIME DATA

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TABLE II

ANALYSIS OF VARIANCE ON MOVEMENT TIME DATA

SOURCES OF VARIATION	df	MS	F
INDEX OF DIFFICULTY (ID)	2	10.68495	1,373.387 **
DIRECTION OF MOVEMENT (D)	6	0.06176	7.938 **
(ID) x (D)	12	0.01745	2.243 *
WITHIN REPLICATES	3129	0.00778	-----
TOTAL	3149		

** $p < 0.01$

* $p < 0.05$

Table III shows the results in graphical form for the Duncan
Multiple Range Test performed on Direction of Movement at p-levels
of significance of 0.01, 0.05, and 0.10 respectively (Ref. 5). This
analysis shows that responses in the 30° direction provide the fastest
mean movement time of the seven directions examined. The table
gives the ranked order of the seven directions of movement, however,
there are a number of homogeneous equivalent subsets at the three
levels of significance. Therefore, a separate ranking is not possible
for the seven different directions examined.

TABLE III

DUNCAL MULTIPLE RANGE TEST

ON MOVEMENT TIME DATA

FOR SEVEN DIRECTIONS OF MOVEMENT

ANGULAR DIRECTION OF MOVEMENT	30°	60°	90°	0°	150°	120°	180°
RANKED ORDER	1	2	3	4	5	6	7
MEAN MOVEMENT TIME	0.353	0.357	0.368	0.369	0.376	0.378	0.386
HOMOGENEOUS SUBSETS[1], p = .01							
ADDITIONAL HOMOGENEOUS SUBSETS[1], p = .05							
ADDITIONAL HOMOGENEOUS SUBSETS[1], p = .10							
DIRECTIONS	30°	60°	90°	0°	150°	120°	180°

[1]Subsets of elements, no pair of which differ by more than the shortest significant range for a subset of that size. All those underlined by the same line can be considered equivalent.

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Regression and correlation analysis were performed on the move-ment time data for each of the seven directions of movement (Ref. 5). The correlation between mean movement time and ID for each of the seven directions of movement was above 0.99. The correlation between mean movement time and ID ranged from a low of 0.992 for 90° to 0.999 for 180° direction of movement. Figures 3-9 show the movement time linear regression equations for each of the seven directions of movement. It appears that ID provides a very good prediction of movement time for dis-crete responses for each of the seven directions reconfirming the results of previous studies by Fitts and Peterson (Ref. 2), Fitts and Radford (Ref. 3), and Breen, DeHaemer, and Poock (Ref. 4).

Finally, a stepwise multiple linear regression was performed on the movement time data (Ref. 5). A level of significance for inclusion of a variable in the equation was set at 0.01. The angles of direction of movement (X) were first transformed by the use of a cosine transgeneration before inclusion in the regression analysis. The resulting equation for predicting movement time is given as follows: $MT = -30.32 + 100.03$ (ID) -3.28 (Cosine X) with a multiple $r = 0.978$. This is a general formula for the prediction of movement time for any of the original angular directions of movement examined. Figures 3-9 show both the simple linear and multiple linear regression equations for predicting movement time for the seven directions of movement.

Non-parametric correlation analysis using the Kendall Rank Cor-relation Coefficient (Υ) was performed between the mean movement times

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of the subjects and their respective IQ's (Ref. 6). This resulted in a $\Upsilon = +0.055$ which is statistically significant at $p = 0.34$ level of significance. A subjective estimate of each of the subject's scholastic performance of duty in school was made for each subject by his (her) teachers. The three teachers estimated the performance of each subject on a scale of 1 -- unsatisfactory to 6 -- outstanding. Similar correlation analysis was performed on IQ versus subjective scholastic performance and mean movement time versus subjective scholastic performance. Results of this analysis showed $\Upsilon = +0.86$ for IQ versus performance and $\Upsilon = -0.065$ for MT versus performance. This indicates that the subjective estimate of scholastic performance is more highly correlated with the subjects' IQ's than with their mean movement times for completing discrete motor tasks in response to visual stimulus. However, since the teachers knew the IQ's of the subjects when they made their subjective scholastic performance ratings, it is possible that the ratings may have been biased by this knowledge.

IV.   DISCUSSION

In the experimentation reported here, seven different directions of movement were examined including the directions to the right and left of the starting position. In previous studies, the information contained in a discrete motor response, the reaction time for the decision process to take place and the movement time to accomplish the response were pooled for responses to the right and left of the starting position. In this investigation each of the seven directions were initially examined separately with the subjects knowing with certainty in which direction they were to move.

The reaction time data for the seven directions demonstrated that direction had no significant effect on the reaction times of the subjects. These results indicated that reaction time is not influenced by the direction in which a subject is going to move. The results reconfirmed the results of previous studies that ID values have a slight effect on reaction time. There was a significant difference at the $p = 0.01$ level of significance. The initial comparison of reaction times showed that the increase in reaction times for increased ID was greatest in angular directions of movement from 90° to 180° while for 0° to 60° the increase in reaction time for an increase in ID was almost negligible. Reaction times for all of the ID's and for all directions of movement were much less than for previous studies which consisted of only right and left movements combined. The ages of the subjects used in this experimentation were from

7 to 13 years younger than those used by Fitts and Peterson (Ref. 2) and 17 to 19 years younger than those used by Breen, DeHaemer and Poock (Ref. 4). The faster reaction times for the subjects reported here seem consistent with Welford's (Ref. 7) conclusion that reaction time and not movement time shows the major effect of aging. The simple linear regression equation for all reaction time data regardless of direction of movement (since direction of movement was not significant) resulted in the following formula: $RT = 5.62 \, (ID) + 222.67$ with a correlation between mean reaction time and ID of 0.64.

The movement time data for the seven directions demonstrated that direction did have a significant effect on the movement time to accomplish the response. The initial comparison of movement time data showed large increases in movement time for increases in ID for each of the seven directions of movement. Statistical analysis reconfirmed that ID had a significant effect on movement time. Both of these results reconfirm the findings of previous studies that reaction time and movement time can be influenced quite independently. The linear regression equations of the form $MT = a + b \, (ID)$ for each of the seven directions reconfirmed the linear relationship between movement time and ID first demonstrated by Fitts and Peterson (Ref. 2).

The Duncan Multiple Range test showed that a completely separate ranking of the seven directions of movement is not possible at 0.01, 0.05, and 0.10 levels of significance. The homogeneous subgrouping at $p = 0.01$ confirms, at least for this experimentation, that the pooling of movement

times for movements to the right and left of a starting position is feasible and a statistically acceptable technique.

The fastest mean movement time occurred for discrete motor responses in the 30° direction of movement for right handed subjects. This resultant direction of movement being faster than any of the other six directions examined is intuitively appealing for right handed subjects.

The major goal of this investigation was to determine the effect of direction of movement on the information capacity of discrete motor tasks in response to visual stimulus. Thus, while the reaction time for the decision process to take place was not affected by direction of movement, the movement time to accomplish the response was significantly affected by the direction in which the response was to be made.

Since the predictive value of the linear regression equations for the seven directions examined here would be of little use to anyone unless he was interested in one of the seven particular directions, a general formula which could be used to accurately predict movement times in any direction from 0° to 180° was developed. A stepwise multiple linear regression analysis was used to incorporate the variables of index of difficulty and direction of movement which were found to significantly affect movement time. The resulting general multiple linear regression formula: $MT = -30.32 + 100.03 \, (ID) - 3.27$ (Cosine of the Angle of Movement) provided the most accurate formula that could be developed with a multiple $r = 0.978$. This formula accounts for both ID and angular direction of movement in predicting movement time to accomplish the response in reaction to visual stimulus.

An examination of the subjects used in this investigation revealed that they possessed IQ's ranging from 95 to 140. The nonparametric statistical analysis conducted using movement times, IQ's, and subjective scholastic performance data tends to demonstrate the possible relative independence of the information capacity required to perform a motor task and the information capacity required to perform academics. The analysis showed that the movement time it took a subject to accomplish a motor response was not highly correlated with the IQ possessed or the academic performance achieved by the subject.

V.   CONCLUSIONS

Conclusions which can be drawn from the results of the experi-
mentation reported here to determine the effects of direction of movement
on the information capacity of discrete motor responses include the
following:

1.   The direction of movement the subject was to move in
response to the visual stimulus had no significant effect on the reaction
time of the discrete motor responses.

2.   A linear regression equation $RT = 222.67 + 5.62$ (ID) might
be used to predict reaction time regardless of the direction in which a
response is to be made.

3.   The equation $MT = a + b$ (ID) first demonstrated by Fitts
and Peterson (Ref. 2) was reconfirmed for each of the seven directions
of movement for visual stimulus.

4.   The direction of movement the subject was to move in
response to the visual stimulus had a significant effect on the movement
times of discrete motor responses of the subjects.

5.   Seven separate simple linear regression formulas which
include the variable of index of difficulty were developed to predict
movement times for the seven directions of movement examined.

6.   A multiple linear regression formula $MT = -30.32 + 100.03$
(ID) $- 3.28$ (Cosine of the Angle of Movement) which contains both of the
variables of ID and angular direction of movement was developed

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which might be used to predict the movement times of discrete motor responses of subjects in.response to visual stimulus.

7. The movement times for completing discrete motor tasks in response to visual stimulus demonstrated a small negative correlation with scholastic performance and a small positive correlation with IQ.

APPENDIX A

INSTRUCTIONS TO SUBJECTS

The experiment in which you are about to participate measures your reaction time and movement time (reaction to the light to your front and movement to a pre-designated target, one of the twenty-one numbered copper disks to your front).

Let me demonstrate to you how to sit at the apparatus and move the probe. You do not have to be afraid or nervous, you will receive no shocks or anything like that. (A short demonstration was presented of how to sit and move the probe in response to a visual stimulus.)

During the experiment, please be sure that you sit erect in the chair, with the copper starting position centered with respect to your body. Your left hand will rest on your lap. Your right hand will grasp the probe as you would a pencil. Place the end of the probe on the center of the starting position, keeping your arm and hand off of the board.

During the experiment, I will tell you to which numbered target I want you to move to next. I will say, "Ready, your next target is target number _____." Locate the target visually. You are to keep the probe in contact with the starting position until the light to your front lights up. When the light comes on, move the probe as rapidly as possible to the pre-designated target. You are simulating the activity of a well-trained operator. Therefore, if you miss the target or otherwise hesitate, please notify me in order that the trial may be attempted again.

Once you move the probe to the target, keep the probe on the target until the light goes off. When this happens, you may return the probe to the starting position and the same procedure will follow again. You may rest between trials.

Do you have any questions? (Questions concerning the procedure were answered.)

Practice trials were run to put subject at ease and insure that he (she) knew exactly what to do during the actual experimentation session.

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13. ABSTRACT

This study reports an investigation designed to determine the effect of direction of movement on the information capacity of discrete motor responses. Reaction times and movement times were measured for thirty right-handed sixth grade students completing discrete motor tasks in response to a visual stimulus. Times for seven different directions over three indexes of difficulty were compared. Results showed that direction had no significant effect on reaction times. Results reconfirmed the findings of previous studies that movement time is a linear function of index of difficulty. In addition, the results showed that direction does have a significant effect on the movement times of discrete motor responses. A multiple linear regression formula: Movement Time = -30.32+100.03 (Index of Difficulty)-3.27 (cosine of the angle of movement); was developed which might be used to predict movement times.

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KEY WORDS	LINK A		LINK B		LINK C	
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information capacity						
reaction time						
movement time						
index of difficulty						
motor responses						